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(54) **GATED IMAGE ACQUISITION AND PATIENT MODEL CONSTRUCTION**

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H05G 1/10	(2006.01)
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CPC A61B 6/481–6/482; A61B 6/032; A61B 6/504; A61B 5/7289; G06T 11/006; G06T 2211/424; H05G 1/58; A61M 5/007; A61M 5/142

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,477,923	A	10/1984	Baumann et al.
4,611,340	A	9/1986	Okazaki
4,672,651	A	6/1987	Horiba et al.
5,019,686	A	5/1991	Marantz
5,583,902	A	12/1996	Bae
5,689,629	A	11/1997	Lee
6,397,098	B1	5/2002	Uber, III et al.
6,697,508	B2	2/2004	Nelson

(Continued)

FOREIGN PATENT DOCUMENTS

CN	101049244	A	10/2007
EP	0486717	A1	5/1992

(Continued)

OTHER PUBLICATIONS

Gordon, et al, Algebraic Reconstruction Techniques (ART) for Three-dimensional Electron Microscopy and X-ray Photography, Dec. 1970, vol. 29, Issue 3, pp. 471-476.*

(Continued)

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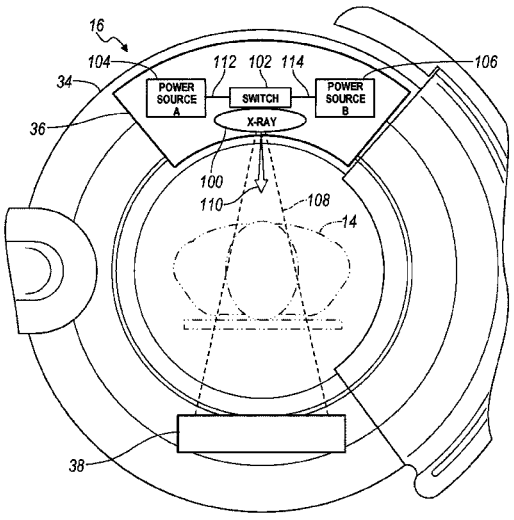
(57) **ABSTRACT**

A method and system is disclosed for acquiring image data of a subject. The image data can be collected with an imaging system with at least two different power characteristics. The image data can be reconstructed using dynamic or enhanced reconstruction techniques.

25 Claims, 3 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

7,852,986	B2	12/2010	Loef et al.	
2003/0050750	A1	3/2003	Kosling et al.	
2003/0152519	A1*	8/2003	Koenig et al.	424/9.41
2003/0161435	A1	8/2003	Ozaki	
2004/0101086	A1	5/2004	Sabol et al.	
2004/0101088	A1*	5/2004	Sabol et al.	378/4
2004/0116804	A1	6/2004	Mostafavi	
2004/0170254	A1	9/2004	Gregerson et al.	
2005/0080327	A1	4/2005	Jenkins et al.	
2005/0084060	A1	4/2005	Seppi et al.	
2005/0171426	A1	8/2005	Rasche	
2005/0201509	A1*	9/2005	Mostafavi et al.	378/8
2006/0052690	A1	3/2006	Sirohey et al.	
2006/0251216	A1	11/2006	Allred et al.	
2007/0009081	A1*	1/2007	Zhou et al.	378/10
2007/0167738	A1	7/2007	Timinger et al.	
2007/0238968	A1*	10/2007	Rappoport et al.	600/407
2008/0123928	A1	5/2008	Harer et al.	
2008/0206150	A1*	8/2008	Louie et al.	424/9.32
2008/0212743	A1*	9/2008	Gregerson et al.	378/197
2008/0232548	A1	9/2008	Tanaka	
2008/0240355	A1	10/2008	Ohishi	
2008/0242978	A1*	10/2008	Simon et al.	600/426
2008/0285722	A1*	11/2008	Bertolina	378/197
2008/0306381	A1	12/2008	Feuerlein et al.	
2009/0010380	A1	1/2009	Gotoh	
2009/0156927	A1*	6/2009	Schmidt	600/420
2009/0232374	A1*	9/2009	Simon	382/131
2010/0046817	A1	2/2010	Goedicke et al.	
2010/0114064	A1	5/2010	Kalafut et al.	
2010/0160776	A1	6/2010	Goto et al.	
2010/0183117	A1	7/2010	Tsumuraya et al.	
2010/0189210	A1	7/2010	Nemoto	
2010/0202585	A1	8/2010	Zaiki	
2010/0290690	A1	11/2010	Hartmann et al.	
2010/0292570	A1	11/2010	Tsukagoshi	
2011/0103542	A1	5/2011	Allmendinger et al.	
2011/0135177	A1	6/2011	Ohishi	
2012/0099768	A1	4/2012	Helm et al.	
2012/0099772	A1	4/2012	Helm et al.	

FOREIGN PATENT DOCUMENTS

EP	1920717	A2	5/2008
JP	2000506398	A	5/2000
JP	2001145619	A	5/2001
JP	2005130929	A	5/2005
JP	2005524419	A	8/2005
JP	2005-536288	A	12/2005
JP	2006296707	A	11/2006
JP	2007143880	A	6/2007
JP	2007519443	A	7/2007
JP	2008096088	A	4/2008
JP	2008253758	A	10/2008
JP	2009056795	A	3/2009
JP	2009119111	A	6/2009
JP	2009131632	A	6/2009
JP	2009-297584	A	12/2009
JP	2009297517	A	12/2009
JP	2010503145	A	1/2010
JP	2010081977	A	4/2010
JP	2010-516401	A	5/2010
JP	2010142478	A	7/2010
WO	WO-2005076810	A2	8/2005
WO	WO-2006034984	A1	4/2006
WO	WO-2009123256	A1	10/2009
WO	WO-2012054733	A2	4/2012
WO	WO-2012054740	A1	4/2012
WO	WO-2012103302	A2	8/2012

OTHER PUBLICATIONS

Montagnat, Johan, and Hervé Delingette. "Globally constrained deformable models for 3D object reconstruction." Signal Processing 71.2 (1998): 173-186.*

"Medtronic O-Arm Multi-Dimensional Surgical Imaging System"; 2009.

International Search Report and Written Opinion mailed Mar. 23, 2012 for PCT/US2011/057121 claiming benefit of U.S. Appl. No. 12/908,200, filed Oct. 20, 2010.

Invitation to Pay Additional Fees and Partial International Search mailed Feb. 23, 2012 for PCT/US2011/057112 claiming benefit of U.S. Appl. No. 13/016,718, filed Jan. 28, 2011; and U.S. Appl. No. 12/908,189, filed Oct. 20, 2010.

Invitation to Pay Additional Fees and Partial International Search mailed Feb. 7, 2012 for PCT/US2011/057121 claiming benefit of U.S. Appl. No. 12/908,200, filed Oct. 20, 2010.

International Search Report mailed Jul. 3, 2012 for PCT/US2011/057112, claiming benefit of U.S. Appl. No. 13/016,718, filed Jan. 28, 2011 and U.S. Appl. No. 12/908,189, filed Oct. 20, 2010.

International Search Report mailed Jul. 20, 2012 for PCT/US2012/022673 claiming benefit of U.S. Appl. No. 13/016,718, filed Jan. 28, 2011.

International Preliminary Report on Patentability and Written Opinion mailed Aug. 8, 2013 for PCT/US2012/022673 claiming benefit of U.S. Appl. No. 13/016,718, filed Jan. 28, 2011.

International Preliminary Report on Patentability and Written Opinion mailed May 2, 2013 for PCT/US2011/057121 claiming benefit of U.S. Appl. No. 12/908,200, filed Oct. 20, 2010.

Chinese Office Action mailed Nov. 2, 2014 for China Patent Document No. 201180061207.4.

Japanese Office Action mailed Nov. 4, 2014 for Japan Patent Document No. 2013-535094.

European Office Action mailed Sep. 22, 2015 for European Patent Application No. 11777009.9.

Second Chinese Office Action mailed May 6, 2015 for China Patent Document No. 201180061219.7.

Second Chinese Office Action mailed Jun. 17, 2015 for China Patent Document No. 201180061207.4.

Japanese Office Action dated Aug. 9, 2016 for Japanese Application No. 2015-017400 for PCT/US2011/057112 which claims benefit of U.S. Appl. No. 13/016,718, filed Jan. 28, 2011 with English translation.

Li "Dual-Energy CT with Fast-kVp Switching and its Applications in Orthopedics" OMICS J Radiology, vol. 2, Issue 6, 8 pages, 2013.

European Office Action dated Mar. 10, 2016 for European Patent Application No. 11779032.9-1666.

European Summons to Attend Oral Proceedings mailed Mar. 6, 2017 for European Patent Application No. 11777009.9 claiming benefit of PCT/US2011/057112 claiming benefit of U.S. Appl. No. 13/016,718, filed Jan. 28, 2011 and U.S. Appl. No. 12/908,189, filed Oct. 20, 2010.

* cited by examiner

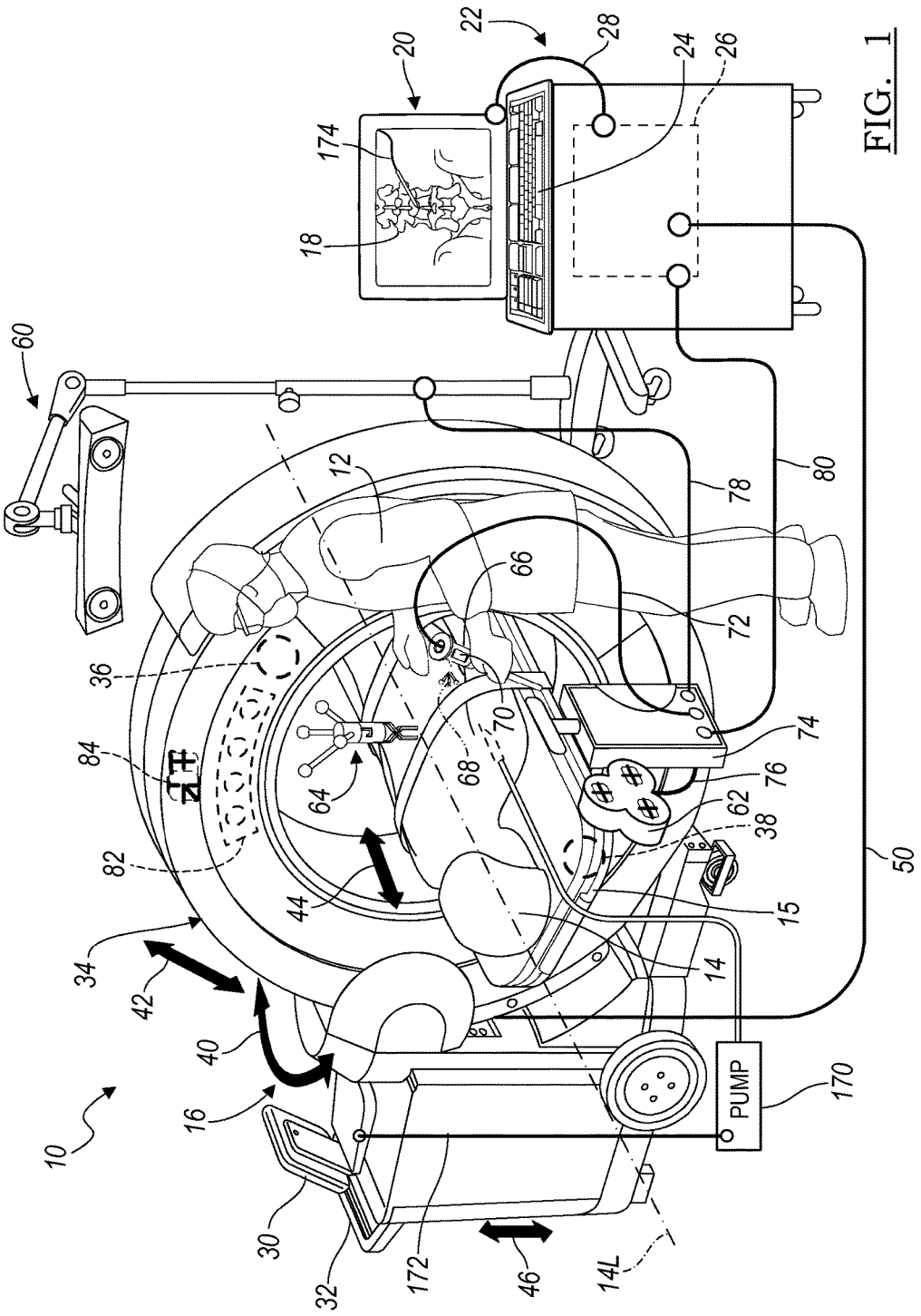

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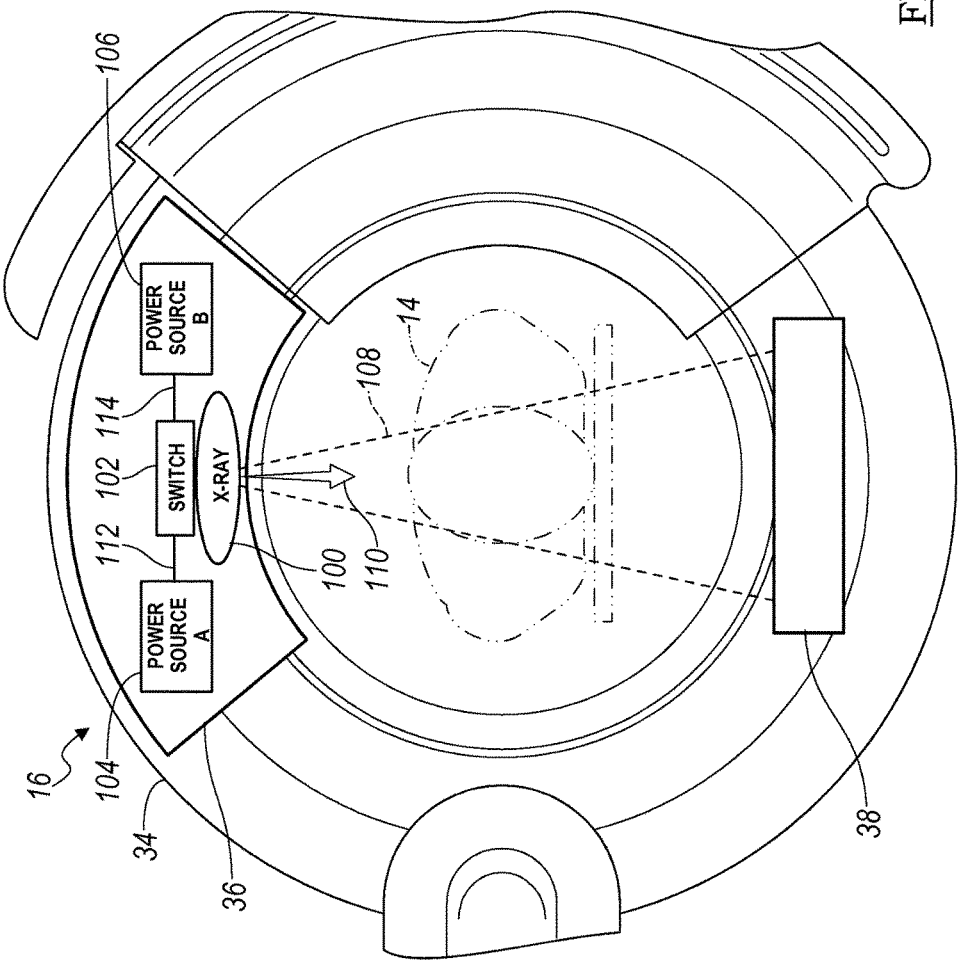
FIG. 1


106
POWER SOURCE B
114
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X-RAY
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POWER SOURCE A
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108
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110
38

FIG. 2

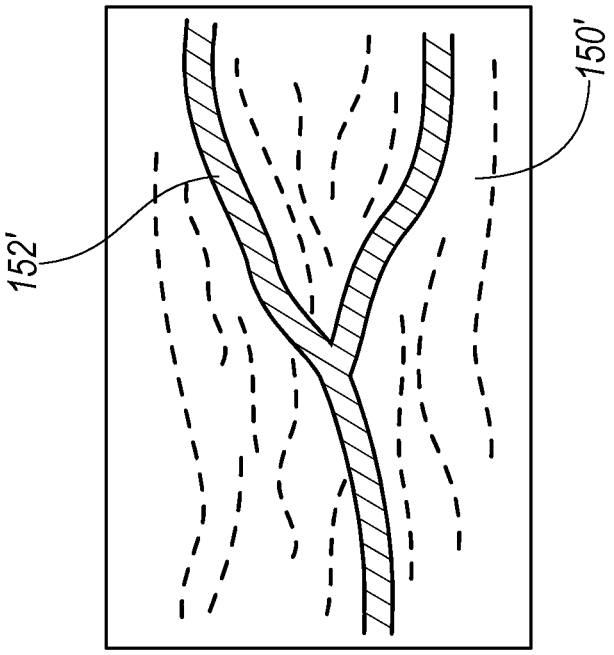

FIG. 3B

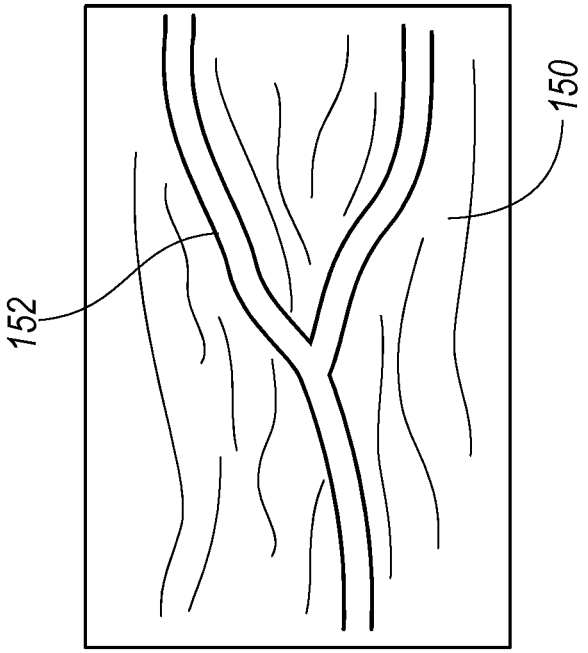

FIG. 3A

GATED IMAGE ACQUISITION AND PATIENT MODEL CONSTRUCTION

FIELD

The present disclosure relates to imaging a subject, and particularly to determining and performing an optimal image data acquisition of the subject to model various physiological characteristic and anatomical features of the subject.

BACKGROUND

This section provides background information related to the present disclosure which is not necessarily prior art.

A subject, such as a human patient, may select or be required to undergo a surgical procedure to correct or augment an anatomy of the patient. The augmentation of the anatomy can include various procedures, such as movement or augmentation of bone, insertion of implantable devices, or other appropriate procedures. A surgeon can perform the procedure on the subject with images of the patient that can be acquired using imaging systems such as a magnetic resonance imaging (MRI) system, computed tomography (CT) system, fluoroscopy (e.g. C-Arm imaging systems), or other appropriate imaging systems.

Images of a patient can assist a surgeon in performing a procedure including planning the procedure and performing the procedure. A surgeon may select a two dimensional image or a three dimensional image representation of the patient. The images can assist the surgeon in performing a procedure with a less invasive technique by allowing the surgeon to view the anatomy of the patient without removing the overlying tissue (including dermal and muscular tissue) when performing a procedure.

SUMMARY

This section provides a general summary of the disclosure, and is not a comprehensive disclosure of its full scope or all of its features.

According to various embodiments, a system to acquire image data of a patient with an imaging system using enhanced contrast imaging can include an imaging system having a first energy source with a first energy parameters and a second energy source with a second energy parameters. The imaging system can also include a pump operable to inject a contrast agent into the patient with an instruction. A controller can be in communication with both the imaging system and the pump. The imaging system can communicate with the pump through the controller regarding timing of the injection of a contrast agent into the patient and is further operable to acquire image data based upon the timing of the injection of the contrast agent and/or the clinical procedure.

Further areas of applicability will become apparent from the description provided herein. The description and specific examples in this summary are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

DRAWINGS

The drawings described herein are for illustrative purposes only of selected embodiments and not all possible implementations, and are not intended to limit the scope of the present disclosure.

FIG. **1** is an environmental view of an imaging system in an operating theatre;

FIG. **2** is a detail view of an imaging system with a dual energy source system;

FIG. **3**A is a schematic representation of non-contrast enhanced image data; and

FIG. **3**B is a schematic representation of a contrast enhanced image data.

Corresponding reference numerals indicate corresponding parts throughout the several views of the drawings.

DETAILED DESCRIPTION

Example embodiments will now be described more fully with reference to the accompanying drawings.

With reference to FIG. **1**, in an operating theatre or operating room **10**, a user, such as a surgeon **12**, can perform a procedure on a patient **14**. In performing the procedure, the user **12** can use an imaging system **16** to acquire image data of the patient **14** for performing a procedure. A model can be generated using the image data and displayed as image data **18** on a display device **20**. The display device **20** can be part of a processor system **22** that includes an input device **24**, such as a keyboard, and a processor **26** which can include one or more processors or microprocessors incorporated with the processing system **22**. A connection **28** can be provided between the processor **26** and the display device **20** for data communication to allow driving the display device **20** to illustrate the image data **18**.

The imaging system **16** can include an O-Arm® imaging system sold by Medtronic Navigation, Inc. having a place of business in Louisville, Colo., USA. The imaging system **16**, including the O-Arm® imaging system, or other appropriate imaging systems in use during a selected procedure are also described in U.S. patent application Ser. No. 12/465,206 filed on May 13, 2009, incorporated herein by reference.

The O-Arm® imaging system **16** includes a mobile cart **30** that includes a control panel or system **32** and an imaging gantry **34** in which is positioned a source unit **36** and a detector **38**. The mobile cart **30** can be moved from one operating theater to another and the gantry **34** can move relative to the cart **30**, as discussed further herein. This allows the imaging system **16** to be mobile thus allowing it to be used in multiple locations and with multiple procedures without requiring a capital expenditure or space dedicated to a fixed imaging system.

The source unit **36** can emit x-rays through the patient **14** to be detected by the detector **38**. As is understood by one skilled in the art, the x-rays emitted by the source **36** can be emitted in a cone and detected by the detector **38**. The source/detector unit **36**/**38** is generally diametrically opposed within the gantry **34**. The detector **38** can move in a 360° motion around the patient **14** within the gantry **34** with the source **36** remaining generally 180° opposed to the detector **38**. Also, the gantry **34** can move isometrically relative to the subject **14**, which can be placed on a patient support or table **15**, generally in the direction of arrow **40** as illustrated herein. The gantry **34** can also tilt relative to the patient **14** illustrated by arrows **42**, move longitudinally along the line **44** relative to a longitudinal axis **14**L of the patient **14** and the cart **30**, can move up and down generally along the line **46** relative to the cart **30** and transversely to the patient **14**, to allow for positioning of the source/detector **36**/**38** relative to the patient **14**. The O-Arm® imaging device **16** can be precisely controlled to move the source/detector **36**/**38** relative to the patient **14** to generate precise image data of the patient **14**. The imaging device **16** can be connected with the processor **26** via connection **50** which can include a wired or wireless connection or physical media

transfer from the imaging system **16** to the processor **26**. Thus, image data collected with the imaging system **16** can be transferred to the processing system **22** for navigation, display, reconstruction, etc.

Briefly, according to various embodiments, the imaging system **16** can be used with an unnavigated or navigated procedure. In a navigated procedure, a localizer, including either or both of an optical localizer **60** and an electromagnetic localizer **62** can be used to generate a field or receive or send a signal within a navigation domain relative to the patient **14**. The navigated space or navigational domain relative to the patient **14** can be registered to the image data **18** to allow registration of a navigation space defined within the navigational domain and an image space defined by the image data **18**. A patient tracker or dynamic reference frame **64** can be connected to the patient **14** to allow for a dynamic registration and maintenance of registration of the patient **14** to the image data **18**.

A patient tracking device or dynamic registration device **64** and an instrument **66** can then be tracked relative to the patient **14** to allow for a navigated procedure. The instrument **66** can include an optical tracking device **68** and/or an electromagnetic tracking device **70** to allow for tracking of the instrument **66** with either or both of the optical localizer **60** or the electromagnetic localizer **62**. The instrument **66** can include a communication line **72** with a navigation interface device **74** as can the electromagnetic localizer **62** with communication line **76** and/or the optical localizer **60** with communication line **78**. Using the communication lines **74**, **78** respectively, the probe interface **74** can then communicate with the processor **26** with a communication line **80**. It will be understood that any of the communication lines **28**, **50**, **76**, **78**, or **80** can be wired, wireless, physical media transmission or movement, or any other appropriate communication. Nevertheless, the appropriate communication systems can be provided with the respective localizers to allow for tracking of the instrument **66** relative to the patient **14** to allow for illustration of the tracked location of the instrument **66** relative to the image data **18** for performing a procedure.

It will be understood that the instrument **66** being any appropriate instrument, such as a ventricular or vascular stent, spinal implant, neurological stent or stimulator, ablation device, or the like. The instrument **66** can be an interventional instrument or can include or be an implantable device. Tracking the instrument **66** allows for viewing the instrument's **66** location relative to the patient **14** with use of the registered image data **18** without direct viewing of the instrument **66** within the patient **14**.

Further, the gantry **34** can include an optical tracking device **82** or an electromagnetic tracking device **84** to be tracked with a respective optical localizer **60** or electromagnetic localizer **62**. Accordingly, the imaging device **16** can be tracked relative to the patient **14** as can the instrument **66** to allow for initial registration, automatic registration or continued registration of the patient **14** relative to the image data **18**. Registration and navigated procedures are discussed in the above incorporated U.S. patent application Ser. No. 12/465,206.

With reference to FIG. **2**, according to various embodiments, the source **36** can include a single x-ray tube **100** that can be connected to a switch **102** that can interconnect a power source A **104** and a power source B **106** with the x-ray tube **100**. X-rays can be emitted generally in a cone shape **108** towards the detector **38** and generally in the direction of the vector **110**. The switch **102** can switch between the power source A **104** and the power source B **106** to power the x-ray tube **100** at different voltages and amperages to emit x-rays at different energies generally in the direction of the vector **110** towards the detector **38**. It will be understood, however, that the switch **102** can also be connected to a single power source that is able to provide power at different voltages and amperages rather than the **102** switch that connects to two different power sources A **104**, and B **106**. Also, the switch **102** can be a switch that operates to switch a single power source between different voltages and amperages. The patient **14** can be positioned within the x-ray cone **108** to allow for acquiring image data of the patient **14** based upon the emission of x-rays in the direction of vector **110** towards the detector **38**.

The two power sources A and B **104**, **106** can be provided within the source housing **36** or can be separate from the source **36** and simply be connected with the switch **102** via appropriate electric connections such as a first cable or wire **112** and a second cable or wire **114**. The switch **102** can switch between the power source A **104** and the power source B **106** at an appropriate rate to allow for emission of x-rays at two different energies through the patient **14** for various imaging procedures, as discussed further herein. The differing energies can be used for material separation and/or material enhanced reconstruction or imaging of the patient **14**.

The switching rate of the switch **102** can include about 1 millisecond to about 1 second, further including about 10 ms to 500 ms, and further including about 50 ms. Further, the power source A **104** and the power source B **106** can include different power characteristics, including different voltages and different amperages, based upon selected contrast enhancement requirements. For example, as discussed further herein, it can be selected to allow for contrast enhancement between soft tissue (e.g. muscle or vasculature) and hard tissue (e.g. bone) in the patient **14** or between a contrast agent injected in the patient **14** and an area without a contrast agent injected in the patient **14**.

As an example, the power source A **104** can have a voltage of about 75 kV and can have an amperage of about 50 mA, which can differ from the power source B which can have a voltage of 125 kV and 20 mA. The selected voltages and amperages can then be switched with the switch **102** to power the x-ray tube **100** to emit the appropriate x-rays generally in the direction of the vector **110** through the patient **14** to the detector **38**. It will be understood that the range of voltages can be about 40 kV to about 80 kV and the amperages can be about 10 mA to about 500 mA. Generally, the power characteristics differences between the first power source A **104** and the second power source B **106** can be about 40 kV to about 60 k V and about 20 mA to about 150 mA.

The dual power sources allow for dual energy x-rays to be emitted by the x-ray tube **100**. As discussed above, the two or dual energy x-rays can allow for enhanced and/or dynamic contrast reconstruction of models of the subject **14** based upon the image data acquired of the patient **14**. Generally an iterative or algebraic process can be used to reconstruct the model of at least a portion of the patient **14** based upon the acquired image data. It will be understood, however, that any appropriate number of power sources or switching possibilities can be provided. Two is included in the subject disclosure merely for clarity of the current discussion.

The power sources can power the x-ray tube **100** to generate two dimension (2D) x-ray projections of the patient **14**, selected portion of the patient **14**, or any area, region or volume of interest. The 2D x-ray projections can be recon-

structed, as discussed herein, to generate and/or display three-dimensional (3D) volumetric models of the patient **14**, selected portion of the patient **14**, or any area, region or volume of interest. As discussed herein, the 2D x-ray projections can be image data acquired with the imaging system **16**, while the 3D volumetric models can be generated or model image data.

Appropriate algebraic techniques include Expectation maximization (EM), Ordered Subsets EM (OS-EM), Simultaneous Algebraic Reconstruction Technique (SART) and Total Variation Minimization (TVM), as generally understood by those skilled in the art. The application to performing a 3D volumetric reconstruction based on the 2D projections allows for efficient and complete volumetric reconstruction. Generally, an algebraic technique can include an iterative process to perform a reconstruction of the patient **14** for display as the image data **18**. For example, a pure or theoretical image data projection, such as those based on or generated from an atlas or stylized model of a "theoretical" patient, can be iteratively changed until the theoretical projection images match the acquired 2D projection image data of the patient **14**. Then, the stylized model can be appropriately altered as the 3D volumetric reconstruction model of the acquired 2D projection image data of the selected patient **14** and can be used in a surgical intervention, such as navigation, diagnosis, or planning. The theoretical model can be associated with theoretical image data to construct the theoretical model. In this way, the model or the image data **18** can be built based upon image data acquired of the patient **14** with the imaging device **16**.

The 2D projection image data can be acquired by substantially annular or 360° orientation movement of the source/detector **36**/**38** around the patient **14** due to positioning of the source/detector **36**/**38** moving around the patient **14** in the optimal movement. Also, due to movements of the gantry **34**, the detector need never move in a pure circle, but rather can move in a spiral helix, or other rotary movement about or relative to the patient **14**. Also, the path can be substantially non-symmetrical and/or non-linear based on movements of the imaging system **16**, including the gantry **34** and the detector **38** together. In other words, the path need not be continuous in that the detector **38** and the gantry **34** can stop, move back the direction from which it just came (e.g. oscilate), etc. in following the optimal path. Thus, the detector **38** need never travel a full 360° around the patient **14** as the gantry **34** may tilt or otherwise move and the detector **38** may stop and move back in the direction it has already passed.

In acquiring image data at the detector **38**, the dual energy x-rays generally interact with a tissue and/or a contrast agent in the patient **14** differently based upon the characteristics of the tissue or the contrast agent in the patient **14** and the energies of the two x-rays emitted by the x-ray tube **100**. For example, the soft tissue of the patient **14** can absorb or scatter x-rays having an energy produced by the power source A **104** differently than the x-rays having energy produced by the power source B **106**. Similarly, a contrast agent, such as iodine, can absorb or scatter the x-rays generated by the power source A **104** differently from those generated by the power source B **106**. Switching between the power source A **104** and the power source B **106** can allow for determination of different types of material properties (e.g. hard or soft anatomy), or contrast agent, implants, etc. within the patient **14**. By switching between the two power sources **104**, **106** and knowing the time when the power source A **104** is used to generate the x-rays as opposed to the power source B **106** to generate the x-rays the information detected at the detector **38** can be used to identify or segregate the different types of anatomy or contrast agent being imaged.

A timer can be used to determine the time when the first power source A **104** is being used and when the second power source B **106** is being used. This can allow the images to be indexed and separated for generating different models of the patient **14**. Also, as discussed herein, the timer, which can be a separate system or included with the imaging system **16** or the processor system **26**, can be used to index image data generated with the contrast agent injected into the patient **14**.

With reference to FIG. **3**A, image data acquired when powering the x-ray tube **100** with the power source **104** is schematically illustrated. As illustrated in FIG. **3**A, the image data can include image data of soft tissue, such as surrounding tissues **150** that surround a vasculature **152**. As illustrated in FIG. **3**A, the power source A **104** can generate x-rays of the x-ray tube **100** that provide substantially little contrast between the vasculature **152** and the surrounding tissue **150**, even if a contrast agent is present in the vasculature agent **152**, such as iodine. With reference to FIG. **3**B, however, the second power source B **106** can be used to generate x-rays with a second energy characteristic to acquire image data that illustrates the surrounding tissue **150'** relative to the vasculature **152'**. This can be further enhanced with a contrast agent that can be injected into the patient **14**. As is understood in the art, the two power levels (e.g. two or more power characteristics) have different attenuations based on the materials in the patient **14**. This differing attenuation can be used to differentiate materials, e.g. vasculature **152** and the surrounding tissue **150**, in the patient **14**.

With the acquisition of the image data illustrated in FIG. **3**A and FIG. **3**B, a reconstruction can be made to clearly identify the vasculature **152** of the patient **14** separate from the surrounding tissue **150** of the patient **14**. The dual energy system can be used to reconstruct a model of the vasculature **152** of the patient **14** to discriminate the vasculature **152** from the surrounding tissue **150** of the patient **14**. In identifying the vasculature **152**, the imaging system **16**, including the O-Arm® imaging system, can be used to efficiently image the vasculature **152** of the patient **14** in the operating theatre **10** during a procedure, such as a valve replacement procedure, a stent procedure, an inclusion ablation procedure, or an angioplasty procedure.

At least because the x-ray tube **100** is in a moveable imaging system, such as the imaging system **16**, it can be moved relative to the patient **14**. Thus, the x-ray tube **100** may move relative to the patient **14** while the energy for the x-ray tube **100** is being switched between the first power source **104** and the second power source **106**. Accordingly, an image acquired with the first power source **104** may not be at the same pose or position relative to the patient **14** as the second power source **106**. If a model is desired or selected to be formed of a single location in the patient **14**, however, various interpolation techniques can be used to generate the model based on the amount of movement of the x-ray tube **100** between when the projection with the first power source **104** and the projection with the second power source **106** was acquired.

The dual energy of the x-rays emitted by the x-ray tube **100** due to the two power sources **104**, **106** can allow for substantially efficient and enhanced contrast discrimination determination between the vasculature **152** and the musculature **150** of the patient **14**. Moreover, the switching by a switch **102** between the power source A **104** and the power

source B **106** allows for an efficient construction of the source **36** where the single x-ray tube **100** can allow for the generation of x-rays at two different energies to allow for enhanced or dynamic contrast modeling of the patient **14**, such as modeling the vasculature of the patient **14** including a contrast agent therein.

The patient **14** can also be imaged with the injected contrast agent by gating the acquisition of the image data of the patient **14** based upon the injection of the contrast agent. According to various embodiments, a contrast agent, such as iodine, can be injected into the patient **14** to provide additional contrast in the image data acquired of the patient **14** with the imaging system **16**. During the image acquisition, however, the contrast agent flows through the vasculature of the patient **14** from an artery phase to a venous phase. For example, the contrast agent can be injected into the patient **14** into an artery where the contrast agent can flow through the vasculature of the patient **14** to the heart, through the heart, to the lungs through the venous system, back through the heart, and out into the arterial portion of the vasculature of the patient **14**.

When acquiring image data of the patient **14** to identify or reconstruct the vasculature of the patient **14**, knowing the timing of when image data is acquired relative to the timing of the injection of the contrast agent can allow for a reconstruction of the various phases based on the known movement of the contrast agent through structures of the patient **14**. In other words, it is generally understood that the contrast agent will flow through the patient **14** as described above at a known or generally known rate. As illustrated in FIG. **3**B, the dual energy x-rays, generated with the x-ray tube **100** based upon the power source A **104** and the power source B **106**, can be used to generate image data of any portion of the vasculature of the patient **14**.

The acquisition of the image data, therefore, can be gated relative to the injection of the contrast agent into the patient **14**. For example, the controls **32** of the imaging system **16** can be associated or communicate with a control of a pump **170** (illustrated in FIG. **1**) through a communication line **172** (illustrated in FIG. **1**) that pumps or injects the contrast agent into the patient **14**. The communication **172** between the pump **170** and the imaging device control **32** can be any appropriate communication such as a wired, wireless, or other data communication system. Also, the control **170** for the pump can be incorporated into the controls **32** of the imaging system **16** or the processor system **26**.

According to various embodiments, the control system **32** for the imaging system **16** can control the pump **170** to initiate injection of the contrast agent into the patient **14**. The imaging system **16** can then acquire image data of the patient **14** over a set period of time to identify the difference between an arterial phase and a venous phase in the patient **14**. For example, the imaging system can control the pump **170** to inject the contrast agent and then acquire image data for approximately 10 seconds to approximately 20 second including approximately 13 seconds. The imaging system **16** can identify or separate a first portion of the image data, such as about 5 second to about 7 seconds, including about 6 seconds as an arterial phase and a second phase of the image data, such as image data acquired after about 6 second to about 8 seconds, including about 7 seconds as a venous phase. In other words, the control system **32**, or other appropriate processor system, can index the image data to determine when the image data was acquired. Also, it will be understood that the image data can be acquired at the two energies. Thus, the controls **32** or other appropriate processing system (e.g. a timer) can index the image data based on which of the two power sources **104**, **106** were used to power the x-ray tube **100**.

After the acquisition of the image data and determining a segregation of time of image data acquisition, a reconstruction of the vasculature of the patient **14** can then be made to illustrate or identify or reconstruct an arterial phase of the patient **14** and separately a venous phase of the patient **14**. Accordingly, the imaging system **16** controlled with the controller **32** can be used to acquire image data of both a venous phase and an arterial phase of the patient **14** in a single image data acquisition sweep or period. In other words, the phase determination and reconstruction of an arterial phase and a venous phase of the vasculature of the patient **14** can be based on a single image data acquisition phase of the patient **14**. Again, this can minimize or limit the exposure of the patient **14** and operating room staff to x-rays emitted from the x-ray tube **100** by requiring only a single image data acquisition phase. It will be understood, however, that a plurality of image data acquisition phases can be acquired of the patient **14**.

The control system **32** of the imaging system **16** can be used to gate acquisition of the image data in addition to or with timing of the pump **170**. For example, it can be selected to acquire image data of the vasculature of the patient **14** during diastole of the heart. During diastole of the heart of the patient **14**, the heart generally does not move and blood in the vasculature is also relatively still. Accordingly, the image data can be acquired of the patient **14** by gating the acquisition of the image data relative to the heart movement of the patient **14**. The generation of the x-rays with the x-ray tube **100** can be switched with the switch **102** to allow for time emission of x-rays from the x-ray tube **100**.

The image data can be acquired by emitting x-rays from the x-ray tube **100** substantially sequentially such that at a selected period of time no x-rays are emitted by the x-ray tube **100** and at a different or second selected time x-rays are emitted from the x-ray tube **100**. The x-rays emitted from one period to another can be at either of the two energies allowed by the power source A **104** or the power source B **106**. Accordingly, at various times no x-rays can be emitted from the x-ray tube **100**, but at other times x-rays can be emitted from the x-ray tube at a selected energy.

In being able to control the image system to emit or not emit x-rays image data acquisition can be gated relative to a physiological event of the patient **14**. It will be further understood that gating of the image acquisition can be based upon respiration of the patient **14**, physical movement of the patient **14**, and other physiological events. The control system **32** can also be used to index the image data regarding whether acquired during a physiological event or not. The physiological event can be determined with an appropriate system, such as an electrocardiogram, or based on a regular rate of image acquisition (e.g. diastole occurs about 2 seconds in the patient **14**).

Also, due to gating of the imaging system **16** relative to the patient **14**, the control system **32** can also be used to control the imaging system **16** to control the speed of the detector **38** relative to the patient **14**. As discussed above, the detector **38** of the imaging system can translate within the gantry **34** of the imaging system **16** to acquire image data of the patient **14**. Further as discussed above, image data can be selected to be acquired of the patient **14** during only selected physiological events, such as diastole of the heart. To generate or form a three-dimensional model of at least a

portion of the patient **14**, it can be selected to have separation of a selected amount between acquisitions of images of the patient **14**.

The detector **38** can be moved at a selected speed and change speeds to ensure appropriate separation of the images during the selected physiological events. The detector **38** can move at a first speed during a first physiological event such as systole of the heart, and at a second speed, such as a greater speed, during diastole of the heart to ensure appropriate separation of acquisition of images of the patient **14** during the selected physiological event.

In generating the 3D volumetric reconstruction to form the model, as discussed above, the model may be multi-phase to illustrate a selected portion of the patient to illustrate a first phase of physiological action and anatomical location and a second phase of physiological action and anatomical location. Thus, the model, or more than one model, can be used to illustrate a first phase (e.g. an arterial phase) and a second phase (e.g. venous phase) of the patient **14**. Also, due to gating and movement of the detector **38** a first position of the detector **38** during image data acquisition and a second position of the detector **38** during image data acquisition can be used in the generating the first model and generating the second model to illustrate more than one phase of a physiological action of the patient **14**. Additionally, the anatomy of the patient **14** and the physiology of the patient **14** can be used to form the 3D reconstruction. For example, the configuration of a bone of the patient **14** or a phase of a heart beat of the patient **14** can be used as a priori knowledge to assist in model reconstruction.

Also, the controller **32** of the imaging system **16** can be used to "rewind" or move the detector **38** back over the same path just traversed by the detector **38**. Even while moving in a selected single path or direction, the detector **38** can be stopped and started, for example for gating or acquiring additional image data (e.g. x-ray projections) at a selected location. Accordingly, the controller **32** can control the imaging system **16** to achieve a selected separation of images relative to the patient **14** for reconstruction of an appropriate or selected model of the patient **14** based upon the required image data.

The reconstruction based on the image data or the raw image data can be used to perform a procedure on the patient **14**. As discussed above selected navigation or tracking systems can be associated with the imaging system **16**. Accordingly, the patient **14** can be registered to the image data and a navigation procedure can be performed. The navigated procedure can include placement of a stent in the patient's **14** heart, brain, or other vasculature, ablation procedures, angioplasty, implant placement or bone resection. Navigation can include tracking or determining automatically a location of an instrument positioned in a navigation field relative to a selected reference frame, such as in patient space, during a surgical procedure. The location of the instrument **66** can be illustrated on the display device **20** with an icon **174** that can be superimposed on the image data or the reconstructed model or image data **18**.

It will also be understood that the image data and/or model can be used to plan or confirm a result of a procedure without requiring or using navigation and tracking. The image data can be acquired to assist in a procedure, such as an implant placement. Also, the image data can be used to identify blockages in the vasculature of the patient **14**, such as with the contrast agent. Thus, navigation and tracking are not required to use the image data in a procedure.

The foregoing description of the embodiments has been provided for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention. Individual elements or features of a particular embodiment are generally not limited to that particular embodiment, but, where applicable, are interchangeable and can be used in a selected embodiment, even if not specifically shown or described. The same may also be varied in many ways. Such variations are not to be regarded as a departure from the invention, and all such modifications are intended to be included within the scope of the invention.

What is claimed is:

1. A method of acquiring image data with an imaging system, comprising:

positioning a movable single x-ray source tube in a housing, wherein the housing is connected to a mobile cart operable to move the housing from a first operating room to a second operating room;

powering the single x-ray source tube with a first power source having a first power characteristic to emit x-rays at a first selected position relative to the patient;

powering the single x-ray source tube with a second power source having a second power characteristic different from the first power characteristic to emit x-rays relative to the first selected position relative to the patient;

gating the powering of the single x-ray source tube with the first power source and the second power source to acquire a plurality of two-dimensional projection image data of the first selected position at both the first power characteristic and the second power characteristic during a first image data acquisition phase at a first time period, wherein gating includes powering the single x-ray source tube to emit x-rays and not powering the single x-ray source tube to not emit x-rays;

indexing the plurality of two-dimensional projection image data to determine a time when each two-dimensional projection image data was acquired; and

operating a processor to execute instructions to reconstruct a first three-dimensional model of a first portion of the patient and a second three-dimensional model of a second portion of the patient based on the acquired plurality of two-dimensional projection image data acquired during the first image data acquisition phase at the first time;

wherein at least one of the first or the second three-dimensional model includes dynamic contrast reconstruction based upon a x-ray attenuation difference in a first tissue and a second tissue based on the two-dimensional image data that is acquired at the first selected position by powering the single x-ray source tube at both the first power characteristic and the second power characteristic;

wherein the first image data acquisition phase at a first time period is configured to generate sufficient image data for operating the processor to execute instructions to reconstruct the first three-dimensional model of the first portion of the patient and the second three-dimensional model of the second portion of the patient;

wherein operating the processor to execute instructions further includes altering a theoretical formed model of the patient, wherein the theoretical model is associated with theoretical two-dimensional image data projections that are used to construct the theoretical model based on a priori knowledge of at least one of a configuration of (i) the first portion of the patient and a second portion of the patient, wherein the first portion includes an arterial portion and the second portion includes a venous portion;

wherein the first power characteristic is selected to be at least one of a first voltage of about 40 kV to about 180 kV and a first amperage of about 10 mA to about 500 mA;

wherein the second power characteristic is selected to be at least one of a second voltage that is about 40 kV to about 60 kV different than the first voltage and a second amperage that is about 20 mA to about 150 mA different than the first amperage.

2. The method of claim **1**, wherein executing instructions with a processor to reconstruct a three-dimensional model includes an iterative process based on at least an anatomy of the patient and a physiological event of the patient;

wherein gating the powering of the single x-ray source tube is based on the physiological event.

3. The method of claim **1**, wherein the three-dimensional model is a model of a heart of the patient, a vasculature of the patient, brain, and combinations thereof.

4. The method of claim **3**, further comprising:

identifying a blockage in the three-dimensional modeled vasculature of the patient; and

performing a procedure on the patient to remove the blockage from the patient;

wherein a contrast agent injected into the patient can be imaged in the image data and used in the three-dimensional model.

5. The method of claim **3**, further comprising:

performing a procedure on the patient including valve localization, valve replacement, aneurysm correction, and combinations thereof.

6. A method of acquiring image data with an imaging system, comprising:

positioning a movable single x-ray source tube in a housing, wherein the housing is connected to a mobile cart operable to move the housing from a first operating room to a second operating room;

providing a first power source to power the single x-ray source tube with a first power characteristic to emit x-rays to acquire a first image data relative to a first selected position for acquisition of the first image data of the patient;

providing a second power source to power the single x-ray source tube with a second power characteristic different from the first power characteristic to emit x-rays to acquire a second image data relative to the first selected position;

moving at least one of the single x-ray source tube or the housing during acquiring the first image data and the second image data based on a selected physiological event of the patient and to acquire the first image data and the second image data of the selected physiological event of the patient;

gating the acquisition of the first image data and the second image data relative to the first selected position at both the first power characteristic and the second power characteristic to acquire the first image data and the second image data at the selected physiological event of the patient including a heart movement of the patient and a timing of an injection of a contrast agent into the patient, wherein gating the acquisition of the first image data and the second image data includes collecting image data of a first phase and a second phase; and

executing instructions with a processor to reconstruct a single three-dimensional model of a portion of the patient using both (a) the first image data acquired at the first power and (b) the second image data acquired at the second power of the acquired physiological event based on (i) an algebraic iterative technique to alter a theoretical formed model of the patient to illustrate one of the first phase or the second phase and (ii) a difference of the first image data at the first power with a first attenuation, including a first x-ray absorption or x-ray scatter in the tissue, and the second image data at the second power with a second attenuation, including a second x-ray absorption or x-ray scatter in the tissue and based on a known timing of acquiring the first image data and the second image data;

wherein the first phase includes an arterial phase and the second phase includes a venous phase;

wherein the first power characteristic is selected to be at least one of a first voltage of about 40 kV to about 180 kV and a first amperage of about 10 mA to about 500 mA;

wherein the second power characteristic is selected to be at least one of a second voltage that is about 40 kV to about 60 kV different than the first voltage and a second amperage that is about 20 mA to about 150 mA different than the first amperage.

7. The method of claim **6**, wherein the physiological event further includes respiration.

8. The method of claim **6**, further comprising:

tracking an instrument relative to the patient;

superimposing an icon representing the instrument on the reconstructed three-dimensional model of the portion of the patient; and

selecting a location of an intervention based on the reconstructed model.

9. The method of claim **8**, further comprising:

selecting an intervention to be at least one of an ablation, a stent implant, an angioplasty, or combinations thereof.

10. The method of claim **6**, wherein moving the at least one of the single x-ray source tube and the housing includes varying a speed of movement of at least one of the single x-ray source tube and the housing over a period of time of the acquisition of the first image data and the second image data based at least in part on the physiological event.

11. The method of claim **10**, wherein the varying speed of movement is dependent on the gating of the acquisition of the first image data and the second image data based on at least one of the timing of an injection of a contrast agent into the patient or the physiological event of the patient.

12. The method of claim **6**, wherein providing a second power source to power the single x-ray source tube with a second power characteristic different from the first power characteristic to emit x-rays relative to the first selected position includes emitting the x-rays at the second power characteristic at a different projection than emitting the x-rays with the first power characteristic.

13. A system to acquire image data of a patient with an imaging system with a duel energy source system, comprising:

a source system including,

a single x-ray source tube,

a first power system having a first power characteristic to power the single x-ray source tube to emit x-rays relating to the first power characteristic;

a second power system having a second power characteristic to power the single x-ray source tube to emit x-rays relating to the second power characteristic; and

a switch to switch between the first power system and the second power system to power the single x-ray source tube;

a detector system positioned to detect x-rays from the source system at both the first power characteristic and the second power characteristic;

a substantially annular gantry associated with both of the detector system and the source system;

an imaging system tracker to track a location of the imaging system including at least one of the source system or the detector;

a control system to control movement of all of the gantry, the detector system, and the source system; and

a reconstruction system operable to execute instructions to generate a three-dimensional model of the at least the portion of the patient based on the image data that is two-dimensional image data acquired at the detector at both the first power characteristic and the second power characteristic to distinguish a soft tissue from a vasculature within the soft tissue based on at least a difference in attenuation of x-rays relating to the first power characteristic and x-rays relating to the second power characteristic in both the soft tissue and the vasculature;

wherein image data is operable to be acquired at a plurality of selected positions relative to at least a portion of the patient at both the first power characteristic and the second power characteristic, wherein the image data is operable to be registered to a patient space of the patient to allow an icon to be superimposed on the registered image data and the generated three-dimensional model of at least the portion of the patient at a location of a tracked instrument relative to the patient without direct viewing of the tracked instrument within the patient based at least on tracking the imaging system tracker;

wherein the reconstruction system operable to execute instructions to generate a three-dimensional model of the at least the portion of the patient further includes altering a theoretical formed model of the patient, wherein the theoretical model of an arterial phase and a venous phase;

wherein the first power characteristic is selected to be at least one of a first voltage of about 40 kV to about 180 kV and a first amperage of about 10 mA to about 500 mA;

wherein the second power characteristic is selected to be at least one of a second voltage that is about 40 kV to about 60 kV different than the first voltage and a second amperage that is about 20 mA to about 150 mA different than the first amperage.

14. The system of claim **13**, further comprising:

a pump operable to pump a contrast agent into the at least the portion of the patient.

15. The system of claim **14**, wherein the control system is configured to gate the image data acquisition, including emitting x-rays and ceasing emission of x-rays, the movement of all of the gantry, the detector system, and the source system all based on both an injection time of the contrast agent from the pump and a physiological event of the patient.

16. The system of claim **13**, further comprising:

a tracking system;

a display device operable to display the three-dimensional model; and

an instrument;

wherein the three-dimensional model is operable to be automatically registered to a patient space of the patient based at least on tracking the imaging system tracker, and wherein a location of the instrument relative to the patient is operable to be tracked with the tracking system and a determined location of the instrument based on the tracked location is operable to be displayed on the display device as an icon superimposed on the three-dimensional model.

17. The system of claim **13**, further comprising:

a memory system having stored thereon instructions for movement of all of the gantry, the detector system, and the source system;

wherein the control system is operable to execute the instructions stored with the memory system to control the movement of all of the gantry, the detector system, and the source system.

18. The system of claim **13**, wherein when the image data is acquired at a plurality of selected positions relative to at least a portion of the patient, a first projection at the first power characteristic is acquired at a first position and a second projection at the second power characteristic is acquired at a second position relative to the patient different from the first position of the first projection due to movement of the detector during switching from the first power characteristic to the second power characteristic.

19. The method of claim **11**, wherein moving at least one of the single x-ray source tube or the housing during an acquisition of the first image data and second image data includes moving at least the x-ray source tube in a non-circular motion.

20. The method of claim **1**, further comprising:

moving the movable single x-ray source tube within a gantry that is configured to annularly encompass the patient at least by moving a mobile cart connected to the gantry, wherein the movable single x-ray source tube is able to move in a 360° motion around the patient within the gantry.

21. The system of claim **13**, wherein the substantially annular gantry substantially encloses both of the detector system and the source system and is configured to move relative to a patient support table.

22. The method of claim **6**, wherein executing instructions with the processor to reconstruct the three-dimensional model of the portion of the patient includes illustrating both the first phase and the second phase as separate anatomical portions.

23. The method of claim **22**, further comprising:

automatically registering the first three-dimensional model and the second three-dimensional mode at least by tracking the at least one single x-ray source tube or the housing;

wherein superimposing the icon representing the instrument includes superimposing the icon on both the first three-dimensional model and the second three-dimensional model.

24. The method of claim **6**, wherein executing instructions with the processor to reconstruct the single three-dimensional model of the portion of the patient further includes interpolation based on an amount of movement of the single x-ray tube between when the first image data was acquired with the first power source and the second image data was acquired with the second power source.

25. The system of claim **14**,

wherein the reconstruction system is further operable to execute instructions to generate a three-dimensional model of at least the portion of the patient based on the image data that is two-dimensional image data acquired at the detector at both the first power characteristic and

the second power characteristic to distinguish between the contrast agent injected into at least the portion of the patient and an area of the patient without the contrast agent.

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